IMPLEMENTATION OF SUPERPAVE MIX DESIGN FOR AIRFIELD PAVEMENTS

By:
L. Allen Cooley, Jr., R. C. Ahlrich, and Robert S. James
Burns Cooley Dennis, Inc.
278 Commerce Park Drive
Ridgeland, MS 39157
USA
Phone: (601) 856-2332; Fax: (601) 856-3552
acooley@bcdgeo.com
rahlrich@bcdgeo.com
rjames@bcdgeo.com

and

Brian D. Prowell and E. Ray Brown
National Center for Asphalt Technology
277 Technology Parkway
Auburn, AL 36830
USA
Phone: (334) 844-6228; Fax (334) 844-6248
prowebd@eng.auburn.edu
brownel@eng.auburn.edu

PRESENTED FOR THE
2007 FAA WORLDWIDE AIRPORT TECHNOLOGY TRANSFER CONFERENCE
Atlantic City, New Jersey, USA

April 2007

ABSTRACT

The Marshall mix design procedure was originally developed in the 1940's for designing hot mix asphalt for airfield pavements. While this mix design procedure has performed well for airfield and highway pavements for over 50 years there is a need to adopt the new Superpave mix design procedure for airfield construction. The primary problem with the Marshall mix design process is that most state DOTs have begun using the Superpave design procedures. Since most asphalt work is done by the DOTs, it is becoming more difficult to find contractors and commercial laboratories having the proper accreditations with the Marshall mix design method. This problem will become much worse in the future. Another problem with the Marshall method of mix design is the higher variability of test results. Studies have shown that the Superpave gyratory compactor provides samples with lower overall variability than samples compacted using the Marshall pedestal and hammer. This lower variability should result in a more consistent design and should allow QC testing to better compare with QA testing. In order to utilize the Superpave mix design system for airfields, guidance is needed on selecting the proper grade of PG binder, aggregate gradation requirements, aggregate quality requirements, proper design compactive effort for various airfield applications, and design volumetric properties.

The objectives of this paper will be to provide guidance on adapting the Superpave mix design system for airfields. This paper will specifically address (1) gradation bands, (2) consensus aggregate properties, (3) volumetric properties and (4) design gyration level. Results from the on-going Airfield Asphalt Pavement Technology Program (AAPTP) Project 04-03 will be utilized to address these various issues.

INTRODUCTION

The SUperior PERforming asphalt PAVEment (Superpave) system was the byproduct of a five year, $50 million research effort conducted on asphalt binders and asphalt paving mixes under the Strategic Highway Research Program (SHRP) [1]. The SHRP program was completed in 1993 and many of the products developed from this research have been adopted by 49 states within the U.S. (California is in the process of adopting). The Superpave mix design methodology and the Superpave asphalt binder tests, which were also developed during SHRP, are currently the most widely used methods in the U.S. for designing hot mix asphalt (HMA) and specifying asphalt binders, respectively. The major emphasis of the asphalt portion of the SHRP program was to develop tests and methods that could be used for designing and specifying HMA for highway applications. Without question, these new tests and methods have greatly increased the quality of HMA on our nation's highways. However, because SHRP was conducted for highway pavements, there is some concern about the implementation of the Superpave mix design methodology and asphalt binder tests for airfield pavements.

Airfield and highway pavements have many similarities, but also have many differences. With respect to specifically flexible pavements, both airfield and highway pavements are designed to transfer loads to the underlying subgrade in a manner that does not overstress the subgrade or create large tensile stresses at the bottom of the asphalt layer. Also, highways and airfields typically utilize the highest quality materials near the pavement surface while material quality generally decreases with depth. The primary differences between highways and airfields are the types of loads and number of loads that are experienced during the design life.

Airfield pavements tend to experience far fewer load repetitions over their design lives than do highway pavements. Table 1 presents the total number of aircraft operations during 1980 at ten selected airports. Though this data is roughly 25 years old, it illustrates that during an average day, many of the busiest airports in the U.S. had less than 2,000 operations. In fact, there are many pavement areas within our nation's busiest airports that may not have a single load applied during the pavement's entire life. For many interstate highways, the average daily traffic can be above 40,000 with heavy truck traffic being in the tens of thousands per day.

Table 1.
Aircraft Operations at Selected Air Carrier Airports in the U.S. in 1980 [2]

	Total aircraft operations				
Airport	Annual	Avg. day	Peak day	Avg. hour	Peak Hour
Chicago O'Hare International	734,555	2012	2639	84	178
Los Angeles International	534,414	1464	1742	61	133
Hartsfield-Atlanta International	609,466	1670	1869	70	145
John F. Kennedy International	311,777	854	1167	36	128
San Francisco International	371,222	1017	1196	42	95
Denver Stapleton International	485,695	1331	1390	55	169
LaGuardia	319,891	876	1125	37	92
Miami International	376,820	1032	1340	43	111
Washington National	354,717	972	1289	41	108
Boston Logan International	340,896	934	1219	39	112

The other primary difference between airfield and highway pavements is the types of loadings [3]. For highways, heavy truck traffic is the primary characteristic used to specify pavement structure and materials. This spectrum of traffic has been quantified by the use of equivalent single axle loads (ESALs) as the controlling factor for both pavement design and selection of HMA materials. For airfields, the pavement is generally designed and specified based upon a design aircraft. Depending upon whether the airport is a small general aviation airport or large commercial airport, the design aircraft can be as small as a Cessna Skyhawk having a gross weight of approximately 3,000 lbs or a Boeing 747 having a maximum take off weight of 870,000 lbs. Another factor related to loads is tire pressure. Small aircraft can have tire pressures similar to automobiles, while some fighter jets can have tire pressures over 300 psi.

Another difference between airfield and highway pavements is the traffic patterns. For highways, the traffic generally is channelized and falls within narrow wheelpaths along the roadway. Traffic patterns on airfields can vary from channelized – moving (taxiways) to channelized-stacked (runway-taxiway ends) to evenly distributed and random (aprons) to occasional (runway edges) to almost never (shoulders and overruns). These various traffic patterns and loading conditions require a need for different HMA mixtures to produce HMA materials that can provide the desired performance.

The primary difference in distresses between airfields and highways is the mode of the distress. A primary highway distress is permanent deformation (rutting) which is load related. Most airfield pavements generally do not have load associated distresses unless the pavement structure was under designed or there were construction related problems. Runways, taxiways and aprons are more prone to raveling and block cracking, which are caused by environmental factors such as oxidation and weathering. In colder climates, thermal cracking is also a serious problem with airfield HMA pavements.

Problem Statement

Historically, airfield and highway pavements have been designed using the Marshall mix design method while in recent years highway pavements have been designed using the Superpave mix design procedure. The Marshall mix design procedure was originally developed in the 1940's for airfield pavements. While this mix design procedure has performed well for airfield and highway pavements for over 50 years, there is a need to adopt the new Superpave mix design procedure.

The primary problem with the Marshall mix design method is that the compaction process does not orient the aggregate in a laboratory compacted sample the same way that it is oriented in the field. This results in a problem when attempting to conduct performance tests since the particle orientation will affect the measured results. The gyratory compactor does a much better job of orienting the aggregate similar to what occurs in the field.

Another problem with the Marshall method of mix design is the higher variability of test results. Studies have shown that the Superpave gyratory compactor provides samples with lower overall variability than samples compacted using the Marshall pedestal and hammer. This lower variability should result in a more consistent design and should allow QC testing to better compare with QA testing.

A third problem with the Marshall mix design process is that most state DOTs have begun using the Superpave design procedures. Since most asphalt work is done by the DOTs, it is becoming more difficult to find contractors and commercial laboratories having the proper accreditations with the Marshall mix design method. This problem will become much worse in the future.

It is desirable to adopt the Superpave mix design procedures for airfield pavements. Superpave was developed for highway pavements, not for airfield pavements, so some modifications to the process are needed prior to adopting for airfields. The Superpave mix design process should not be adopted without some research to identify the specific procedures to be used for airfields. The compactive effort in the mix design procedure should be a function of traffic level, traffic loads, speed of traffic, tire pressures, etc.

Guidance is needed on selecting the grade of PG binder, aggregate gradation requirements, aggregate quality requirements, appropriate number of gyrations, and use of N_{ini} and N_{max}. The aggregate requirements for airfields have been developed over a period of many years and provided good mixes in the past. It is not anticipated that significant changes will be made to the aggregate requirements. The primary focus of this study will be to determine the specific methods that should be used to establish the optimum asphalt content for various airfield traffic levels. This guidance has to be based on the traffic level such as that for general aviation, heavy duty airports, and military airfields. Also a comparison of the moisture susceptibility testing requirements for airfield mixtures should be made with the more generally accepted method of moisture susceptibility testing.

OBJECTIVES

The objectives of this paper are to provide guidance on adapting the Superpave mix design system for airfields. This paper will specifically provide a critical comparison between typical airfield HMA mix design methods and the Superpave mix design system. Additionally, this paper will address (1) gradation bands, (2) aggregate requirements, (3) volumetric properties, and (4) design gyration levels.

CRITICAL COMPARISON OF MIX DESIGN SPECIFICATIONS

The primary hot mix asphalt (HMA) mix design specifications utilized for airfield pavements include Item P-401 documented in the Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5370-10B and the Department of Defense (DoD) Unified Facilities Guide Specification (UFGS)-32 12 15 (formerly UFGS-02749). Item P-401 is utilized on most civilian airfields. However, the HMA used on many general aviation airfields is designed using local specifications because of the relatively light aircraft and the relatively few operations. The UFGS-32 12 15 is utilized to design HMA for military airfields.

Hot mix asphalt for highway pavements is most commonly designed in accordance with the Superpave mix design method as outlined in AASHTO M323, “Standard Specification for Superpave Volumetric Mix Design.” Practically every State Department of Transportation has adopted the Superpave mix design method for designing HMA for highways. From a production standpoint, this means that the majority of HMA produced in the U.S. is designed using the Superpave mix design method.

General

All three of the HMA mix design specifications mentioned above have a similar goal: develop the right volumetric proportion of aggregates, asphalt binder, and air voids. By designing an HMA with the right volumetric proportions, the pavement structure the HMA is placed on should perform with respect to stability and durability. Each method includes basically the same four steps: 1) select acceptable materials (aggregates and asphalt binder); 2) blend the selected materials to meet specifications; 3) select an appropriate optimum asphalt binder content; and 4) evaluate the designed mixture for moisture susceptibility.

Selection of Materials

Materials used in the design of dense-graded HMA include coarse aggregates, fine aggregate, asphalt binder, and other materials that may be required to meet the mix design specifications. In some instances, mineral fillers are needed if local aggregates do not contain a sufficient amount of material passing the 0.075mm (No. 200) sieve. When local materials have a high potential for moisture susceptibility, anti-stripping additives are also commonly used within the HMA. The following sections discuss the material requirements for the mix design methods.

Coarse Aggregates

All three mix design specifications have requirements to ensure the desired coarse aggregate particle angularity and shape. All three methods also utilize similar test methods (Table 2), with only slight deviations in the actual requirements. For coarse aggregate angularity, the percent fractured faces is used. The primary difference is that the historical airfield mix design specifications utilize a slightly different definition for fractured faces than does the Superpave specifications. The airfield specifications define a fractured face as an area equal to at least 75 percent of the smallest mid-sectional area of the particle. Using the Superpave specified ASTM D5821, Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate, a fractured face is at least 25 percent of the maximum projected area. In essence, these two definitions of a fractured face are practically the same because all three specifications minimize the percentage of flat and elongated particles.

Table 2.
Coarse Aggregate Requirements Summary

	Mix Design Specification		
Characteristic	P-401	UFGS-32 12 15	Superpave
Angularity	Fractures Faces	Fractures Faces	Fractures Faces
Shape	Flat, Elongated & Flat and Elongated	Flat and Elongated	Flat and Elongated
Toughness	LA Abrasion	LA Abrasion	Individual Agency
Soundness	Sulfate	Sulfate	Individual Agency
Cleanliness	Deleterious Materials	Deleterious Materials	Individual Agency

As stated above, all three specifications control the percentage of flat and elongated particles, resulting in relatively cubical coarse aggregates. The primary differences are the ratio at which the particles are compared and the characteristics being evaluated (flat, elongated, and flat and elongated).

The primary difference between the three mix design specifications related to coarse aggregate is that Item P-401 and UFGS-32 12 15 have requirements for toughness, soundness and deleterious materials. The Superpave specification does not have explicit requirements for these properties; however, they are recognized as important [1]. Within the Superpave mix design system, toughness, soundness and deleterious materials are considered “source” properties and specified values are set by local agencies with knowledge of local materials.

Based upon this discussion, requirements for coarse aggregate within the three mix design specifications are very similar. This is especially true when considering that the source properties (Los Angeles Abrasion, sulfate soundness and deleterious materials) are specified by most highway agencies when designing HMA using the Superpave system.

Fine Aggregates

Based upon the three mix design specifications, all provide requirements for fine aggregate angularity and cleanliness (Table 3). The primary differences between the three include the specified maximum allowable percentage of natural, uncrushed sand contained within Item P-401 and UFGS-32 12 15 and the requirements within Item P-401 that the parent aggregates used to create the fine aggregate meet toughness and soundness requirements presented earlier.

Table 3.
Fine Aggregate Requirements Summary

	Mix Design Specification		
Characteristic	P-401	UFGS-32 12 15	Superpave
Angularity	Max % Natural Sand	Max % Natural Sand Uncompacted Voids	Uncompacted Voids
Toughness	LA Abrasion (parent aggregate)	___	___
Soundness	Sulfate (parent aggregate)	___	___
Cleanliness	Sand Equivalency Plastic Limit Liquid Limit	Sand Equivalency Deleterious Mat'ls	Sand Equivalency

Asphalt Binder

All three mix design specifications allow the use of Performance Graded (PG) asphalt binders meeting the requirements of AASHTO M320, "Performance Graded Asphalt Binder." Item P-401 and UFGS-32 12 15 also allow viscosity and penetration graded binders. Research project AAPTP 04-02, "PG Binder Selection for Airfield Pavements," is addressing the asphalt binder issue for airfields.

Blending the Selected Materials

Once materials have been selected, the next step in all three mix design methods is to blend the materials. This step predominately entails blending the selected coarse and fine aggregate stockpiles to meet the respective gradation requirements. Tables 4 through 6 present the gradation requirements for Item P-401, UFGS-32 12 15, and Superpave, respectively.

Table 4.
Item P-401 Gradation Requirements

Sieve Size U.S. (mm)	Percentage by Weight Passing Sieves			
	1 – ½”max	1’ max	3/4” max	½” max
1-1/2 (37.5)	100	---	---	---
1 (25.0)	86-98	100	---	---
¾ (19.0)	68-93	76-98	100	---
½ (12.5)	57-81	66-86	79-99	100
3/8 (9.5)	49-69	57-77	68-88	79-99
No. 4 (4.75)	34-54	40-60	48-68	58-78
No. 8 (2.36)	22-42	26-46	33-53	39-59
No. 16 (1.18)	13-33	17-37	20-40	26-46
No. 30 (0.600)	8-24	11-27	14-30	19-35
No. 50 (0.300)	6-18	7-19	9-21	12-24
No. 100 (0.150)	4-12	6-16	6-16	7-17
No. 200 (0.075)	3-6	3-6	3-6	3-6

Table 5.
UFGS-32 12 15 Gradation Requirements

Sieve Size, inch (mm)	Gradation 1	Gradation 2	Gradation 3
	Percent Passing by Mass	Percent Passing by Mass	Percent Passing by Mass
1 (25.0)	100	---	---
¾ (19.0)	76-96	100	---
½ (12.5)	68-88	76-96	100
3/8 (9.5)	60-82	69-89	76-96
No. 4 (4.75)	45-67	53-73	58-78
No. 8 (2.36)	32-54	38-60	40-60
No. 16 (1.18)	22-44	26-48	28-48
No. 30 (0.6)	15-35	18-38	18-38
No. 50 (0.3)	9-25	11-27	11-27
No. 100 (0.15)	6-18	6-18	6-18
No. 200(0.075)	3-6	3-6	3-6

Item P-401 provides four gradation bands through which the blended aggregates must pass. The gradations are labeled based upon maximum aggregate size. For the purposes of Item P-401, the maximum aggregate size is the sieve one size larger than the first sieve to retain material. Gradation bands within Item P-401 are provided for 1 ½ in., 1 in., ¾ in, and ½ in. maximum aggregate sizes. The UFGS-32 12 15 specification provides three gradation bands that are simply labeled as Gradation 1, Gradation 2, and Gradation 3 Based upon the definition of maximum aggregate size utilized in Item P-401, these three gradations would have a maximum aggregate size of 1 in., ¾ in. and ½ in. A total of six gradation requirements are provided within the Superpave mix design specification. Within the Superpave specification, gradation requirements are based upon control points instead of gradation bands. The control points are less restrictive than full gradation bands as generally the gradation is only limited on four sieve sizes. Another

Table 6.
Superpave Aggregate Gradation Control Points

Sieve Size, inch	Nominal Maximum Aggregate Size – Control Points (Percent Passing)											
	37.5 mm		25.0mm		19.0mm		12.5mm		9.5mm		4.75mm	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2.0	100	---	---	---	---	---	---	---	---	---	---	---
1.5	90	100	100	---	---	---	---	---	---	---	---	---
1.0	---	90	90	100	100	---	---	---	---	---	---	---
¾	---	---	---	90	90	100	100	---	---	---	---	---
⅛	---	---	---	---	---	90	90	100	100	---	100	---
⅜	---	---	---	---	---	---	---	90	90	100	95	100
No. 4	---	---	---	---	---	---	---	---	---	90	90	100
No. 8	15	41	19	45	23	49	28	58	32	67	---	---
No. 16	---	---	---	---	---	---	---	---	---	---	30	60
No. 200	0	6	1	7	2	8	2	10	2	10	6	12

difference is how gradations are defined. Within the Superpave mix design system, gradations are identified based upon nominal maximum aggregate size. Nominal maximum aggregate size (NMAS) is defined as one sieve size larger than the first sieve that retains (total) more than 10 percent aggregate [1]. Put another way, the NMAS is one sieve size larger than the first sieve that has less than 90 percent of the blend passing. The maximum aggregate size is simply one sieve size larger than the NMAS.

Comparison of Tables 4 through 6 indicates that the Superpave specification is the only to have gradation requirements for a 2 in. maximum aggregate size (37.5 mm NMAS). Both Item P-401 and Superpave have requirements for a 1 ½ in. maximum aggregate size gradation (25.0mm NMAS). The gradation requirements are very similar on the 2.36 mm (No. 8) sieve for these two gradation specifications. However, because the Superpave requirements do not have control points between the 25.0 (1 in.) and 2.36 mm sieves, the Superpave gradation requirements are much less restrictive than Item P-401.

Of the three 1 in maximum aggregate size (19.0mm NMAS)) specifications, the UFGS-32 12 15 specification allows the finest gradation, while the Superpave specification allows the coarsest. The Item P-401 gradation band resides totally within the Superpave control points on the 2.36 mm sieve. The UFGS-32 12 15 gradation band is above the Superpave upper control point on the 2.36 mm sieve signifying the allowance of finer gradations. As for the lower Superpave control point, the UFGS-32 12 15 gradation band is 9 percent finer than the Superpave specification and 5 percent finer than the Item P-401 specification. Both the Item P-401 and UFGS-32 12 15 have a range of 3 to 6 percent passing the 0.075 mm (No. 200) sieve, while the range within the Superpave specification is 2 to 8 percent.

Similar to the 1 in. maximum aggregate size gradation requirements, UFGS-32 12 15 allows the finest gradation and Superpave allows the coarsest for the ¾ in maximum aggregate size gradations (12.5mm NMAS). The Item P-401 gradation band is totally included within the Superpave control points on the 2.36 mm sieve. The UFGS-32 12 15 lower limit on the 2.36 mm sieve is 10 percent finer than the Superpave lower control point and Item P-401 is 5 percent finer than the Superpave lower control point. Again, both Item P-401 and UFGS-32 121 5 have an allowable range of 3 to 6 percent passing on the 0.075 mm sieve while the Superpave control points allow 2 to 10 percent.

Unlike the two previous two gradations sizes, Item P-401 and UFGS-32 12 15 reside totally within the Superpave control points on the 2.36 mm sieve for the ½ in maximum aggregate size gradation (9.5mm NMAS) specifications. Therefore, HMA designed in accordance with the Superpave specifications for a ½ in. maximum aggregate size can be either finer or coarser than the two historical airfield specifications. Similar to other gradation sizes, Item P-401 and UFGS-32 12 15 are more restrictive on the percentage of material passing the 0.075 mm sieve with a range of 3 to 6 percent. The Superpave specification for ½ in. maximum aggregate size gradation on the 0.075 mm sieve is a range of 2 to 10 percent.

The Superpave specification is the only one of the three that includes gradation requirements for a 3/8 in. maximum aggregate size (4.75mm NMAS).

The Superpave mix design specification provides the most potential gradation sizes with six maximum aggregate sizes. Item P-401 provides requirements for four gradation sizes, while UFGS-32 12 15 provides three gradation bands. Where comparisons can be made, the UFGS-32 12 15 gradation requirements generally allow the finest gradations on the 2.36mm sieve, while the Superpave specifications always allow the coarsest gradations. The two historical airfield specifications are much more restrictive in the potential gradations that can be blended than Superpave. By using relatively few control points, the Superpave gradation requirements are much less restrictive, especially for larger maximum aggregate size gradations.

Select Appropriate Optimum Asphalt Binder Content

Once appropriate materials have been selected and the aggregates blended to meet the desired gradation, all three mix design specifications involve adding asphalt binder to the aggregates and performing laboratory compaction in order to evaluate the mixture's volumetric properties. The primary difference between the mix design specifications is the method of laboratory compaction. Item P-401 and UFGS-32 12 15 both specify the use of the Marshall hammer in accordance with Chapter 5 of the Asphalt Institute's MS-2, "For Asphalt Concrete and Other Hot Mix Types" [4]. The Superpave mix design specifications require the use of the Superpave gyratory compactor (SGC) for the laboratory compaction of HMA during design.

The compactive effort utilized in all three mix design specifications is controlled by the anticipated loadings on the pavement. Within Item P-401, the design compactive effort is based upon the design aircraft gross weight and/or tire pressure. For design aircraft over 27,200 kg (60,000 lbs) or landing gear tire pressure of 690 kPa (100 psi), a design laboratory compactive effort of 75 blows per face of the Marshall hammer is used. Pavements designed for aircraft less than 27,200 kg or tire pressure less than 690 kPa are designed using 50 blows per face. Within UFGS-32 12 15, the design laboratory compactive effort is based upon landing gear tire pressure and location on the airfield. Similar to Item P-401, the HMA used on pavements designed for aircraft having tire pressure greater than 690 kPa are to be designed using 75 blows per face of the Marshall hammer. Pavements designed for aircraft having the pressures less than 690 kPa are to be designed using 50 blows per face. UFGS-32 12 15 does, however, provide a stipulation that HMA used on shoulders should be designed using 50 blows per face.

The design compactive effort within the Superpave mix design specification is also based upon expected loadings. Within Superpave, the design compactive effort is defined as the design number of gyrations (N_{design}) in the SGC. Pavements designed for heavier or more loadings are designed using more gyrations. Currently, there are four design gyrations levels within Superpave 50, 75, 100 and 125 gyrations. The lowest, 50 gyrations, is generally specified for low volume pavements, while the highest, 125 gyrations, is generally specified for pavements with a high volume of heavy loadings.

As stated previously, all three specifications include volumetrics in the selection of the optimum asphalt binder content. Volumetric properties, such as voids in total mix (generally called air voids), voids in mineral aggregate (VMA), and voids filled with asphalt (VFA) are all included within the three specifications. Samples of HMA are compacted using the design compacted effort at varying asphalt binder contents. The volumetric properties of each sample are then determined and compared to specification limits. This is true for all three mix design specifications.

An added feature to the mix design process, when using the Marshall hammer, is the measurement of Marshall stability and flow. These two tests are utilized as proof tests on the designed mix. Both Item P-401 and UFGS-32 12 15 include a minimum value of Marshall stability and a range of allowable flow values.

Marshall Mix Design Method

In order to select optimum asphalt binder content using the Marshall method of mix design, the relationships between asphalt binder content and air voids, VMA and stability are developed. The next step is to select an asphalt binder content that meets all requirements, similar to Figure 7. Though Item P-401 and UFGS-32 12 15 both utilize the Marshall mix design method, the specified criteria within these two specifications are slightly different. Tables 7 and 8 present the mix design criteria for Item P-401 and UFGS-32 12 15, respectively. The primary differences between these two specifications are the design air void range and the allowable range in flow values. Item P-401 allows optimum asphalt binder contents between 2.8 and 4.2 percent air voids, while the UFGS-32 12 15 specification has a range of 3 to 5 percent air voids for selection of optimum asphalt binder content. Requirements for flow values within Item P-401 range from 10 to 14 while within UFGS-32 12 15 the allowable range is 8 to 16.

Also included within Tables 7 and 8 is a reference to Table 9. Table 9 presents the minimum VMA requirements within both Item P-401 and UFGS-32 12 15. As shown in Table 9, there are differences in the minimum VMA requirements. Item P-401 requires 1.0 percent more VMA than UFGS-32 12 15 for a given maximum aggregate size gradation.

Table 7.
Marshall Design Criteria - Item P-401

Test Property	Pavements Designed for Aircraft Gross Weight of 60,000 lbs or More or Tire Pressures of 100 psi or More	Pavements Designed for Aircraft Gross Weights Less than 60,000 lbs. or Tire Pressures Less Than 100 psi
Number of Blows	75	50
Stability, pounds (newtons)	2150 (9564)	1350 (6005)
Flow, 0.01 in. (0.25 mm)	10-14	10-18
Air Voids (percent)	2.8-4.2	2.8-4.2
Percent VMA (minimum)	See Table 9	See Table 9

Table 8.
Marshall Design Criteria - UFGS-32 12 15

Test Property	75 Blow Mix	50 Blow Mix
Stability, Newtons minimum	9560	6000
Flow, 0.25mm	8-16	8-18
Air voids, percent	3-5	3-5
Percent VMA (minimum)	See Table 9	See Table 9
Dust Proportion	0.8-1.2	0.8-1.2
TSR, Minimum Percent	75	75

Table 9.
Minimum Percent Voids in Mineral Aggregate

Maximum Particle Size		Minimum VMA P-401	Minimum VMA UFGS-32 12 15
in.	mm		
½	12.5	16.0	15.0
¾	19.0	15.0	14.0
1	25.0	14.0	13.0
1-1/2	37.5	13.0	-

UFGS-32 12 15 includes a specification range for dust proportion, 0.8 to 1.2, that is not included in Item P-401. Dust proportion is calculated as the percent aggregate mass passing the 0.075mm (No. 200) sieve divided by the effective asphalt binder content.

The optimum binder content is selected as an asphalt binder content that meets all volumetric criteria as well as stability and flow. If any of the volumetric properties, stability or flow are not met, modifications to the materials and/or blend must be made.

Superpave Mix Design Method

Similar to the Marshall method, samples must be compacted at varying asphalt binder contents to the design compactive effort (N_{design}). Unlike the Marshall mix design method, the

Superpave method involves selection of optimum asphalt binder content based solely on volumetric properties (i.e., no proof test).

Volumetric properties included within the evaluation include air voids, VMA and VFA just as in the Marshall method (Table 10). Dust proportion is also included, similar to UFGS-32 12 15. However, there are two volumetric properties included in the Superpave mix design method that are not included in the Marshall method: percent theoretical maximum density at the initial number of gyrations (%G_{mm}@$N_{initial}$) and percent theoretical maximum density at the maximum number of gyrations (%G_{mm}@$N_{maximum}$). Unlike the impact of the Marshall hammer, the SGC kneads the HMA during compaction. During this kneading compaction, the SGC records the height of HMA after every gyration. This allows for the evaluation of the HMA at various gyration levels. The design number of gyrations is equivalent to 50 blows or 75 blows in the Marshall method in that N_{design} is used to evaluate volumetric properties and pick optimum asphalt binder content. Requirements for $N_{initial}$ are included within Superpave in an effort to prevent tender HMA mixes during construction. High values of %G_{mm}@$N_{initial}$ indicated a mixture that compacts readily. Requirements for $N_{maximum}$ are provided to identify HMA mixes that may continue to compact over time resulting in a rut prone mixture.

Table 10.
Superpave HMA Design Criteria

Design ESALs[a] (Million)	Required Relative Density, Percent of Theoretical Maximum Specific Gravity			Voids in the Mineral Aggregate (VMA), Percent Minimum Maximum Aggregate Size, mm						Voids Filled with Asphalt (VFA) Range,[b] Percent	Dust-to-Binder Ratio Range[c]
	$N_{initial}$	N_{design}	N_{max}	2	1.5	1	¾	½	3/8		
<0.3	≤91.5	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	70-80[d]	0.6-1.2
0.3 to <3	≤90.5	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	65-78	0.6-1.2
3 to <10	≤89.0	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	65-75[e]	0.6-1.2
10 to <30	≤89.0	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	65-75[e]	0.6-1.2
≥30	≤89.0	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	65-75[e]	0.6-1.2

[a]Design ESALs are the anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs or 20 years.

[b]For 37.5-mm nominal maximum size mixtures, the specified lower limit of the VFA range shall be 64 percent for all design traffic levels.

[c]For 4.75-mm nominal maximum size mixtures, the dust-to-binder ratio shall be 0.9 to 2.0.

[d]For 25.0-mm nominal maximum size mixtures, the specified lower limit of the VFA range shall be 67 percent for design traffic levels <0.3 million ESALs.

[e]For design traffic levels >3 million ESALs, 9.5-mm nominal maximum size mixtures, the specified VFA range shall be 73 to 76 percent and for 4.75-mm nominal maximum size mixtures shall be 75 to 78 percent.

Similar to the Marshall method, the relationships between asphalt binder content and the various volumetric properties are developed. Optimum asphalt binder content is defined as the asphalt binder content that results in 4.0 percent air voids. At this asphalt binder content, all properties shown in Table 10 must be met for the appropriate design traffic level. If any volumetric properties do not meet requirements, the materials and/or gradation must be altered.

Summary of Comparison for Selection of Optimum Asphalt Binder

Both the Marshall mix design method utilized in Item P-401 and UFGS-32 12 15 and the Superpave mix design method rely on volumetric properties to select the optimum asphalt binder content for an HMA. The volumetric properties air voids, VMA and VFA are all included. Voids filled with asphalt are not directly included within Item P-401; however, VFA is indirectly specified because of the requirements on air voids and VMA.

Item P-401 and UFGS-32 12 15 both allow the mix designer to select the optimum asphalt binder content based upon a range of air voids, while the Superpave mix design system requires selection of optimum asphalt at 4.0 percent voids. Likely the biggest difference in selecting optimum asphalt is the method of compaction. Item P-401 and UFGS-32 12 15 specify the Marshall hammer which compacts the HMA through impact. The Superpave mix design system specifies a Superpave gyratory compactor which compacts the HMA through kneading. An added benefit of the SGC is that the compaction characteristics of the HMA can be evaluated. This has resulted in two additional volumetric properties that are evaluated during selection of optimum asphalt: $\%G_{mm}@N_{initial}$ and $\%G_{mm}@N_{maximum}$. Another major difference is that Item P-401 and UFGS-32 12 15 both utilize Marshall stability and flow as a proof test. Currently, there is no proof test within Superpave.

Comparison of Moisture Susceptibility Requirements

The final step in all three mix design methods is to evaluate the designed mix for moisture susceptibility. All three methods utilize tensile strength ratios to define moisture susceptibility. Both Item P-401 and UFGS-32 12 15 specify ASTM D4867, "Effect of Moisture on Asphalt Concrete Paving Mixtures," to indicate the potential for moisture damage. Both also require a minimum tensile strength ratio of 75 percent. The Superpave mix design specification requires the use of AASHTO T283, "Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage," for measuring moisture susceptibility. A minimum tensile strength ratio of 80 percent is required for Superpave designs.

Summary of Critical Comparison

All three mix design specifications have many similarities. All include four primary steps, selection of materials, blending of selected materials, selection of optimum asphalt binder content and evaluation of moisture susceptibility. Each method has aggregate property criteria to ensure angular and clean aggregates that are properly shaped. All three specifications also ensure tough and durable aggregates; though, local agencies specify appropriate toughness and durability criteria within Superpave. With respect to asphalt binders, all three allow the use of Performance Graded asphalt binders.

There are minor differences in how the aggregates can be blended. The Superpave gradation requirements allow for the most gradation options (maximum aggregate sizes). For a given maximum aggregate size gradation, use of the Superpave control points also allows for the most gradation shapes. The two historical airfield specifications are much more restrictive because of the use of gradation bands. The UFGS-32 12 15 specification generally allows the finest gradations, while the Superpave specification allows the coarsest.

The biggest difference in designing HMA is that the two historical airfield specifications require laboratory compaction with the Marshall hammer, while the Superpave specification requires the Superpave gyratory compactor. These two methods of laboratory compaction are very different. Another difference is that the two airfield specifications utilize Marshall stability and flow as a proof test during mix design. Superpave does not currently include a proof test. When selecting optimum asphalt, all three methods are similar in that volumetrics are used. Air voids, VMA and VFA are all directly or indirectly specified. There are slight differences in the specified volumetric requirements; however, the biggest of which is the use of a range in design air voids within the Marshall methods.

With respect to moisture susceptibility, all three methods utilize tensile strength ratio to provide a measure of moisture damage potential. The methods specified have slight differences, but the underlying test method is the same. Specification values only differ slightly.

In summary, the three mix design specifications have many similarities. Without question, the goal of each mix design method is to produce an HMA that is stable and durable for its intended purpose. The primary issues that must be addressed as part of AAPTP 04-03 are the laboratory compactive effort, appropriate volumetric criteria for selection of optimum asphalt, appropriate gradation sizes and shapes for airfields, method and criteria for evaluating moisture susceptibility and appropriate test method and criteria for materials selection.

REFERENCES

1. Cominsky, R.J., Huber, G.A., Kennedy, T.W., and Anderson, M., “The Superpave Mix Design Manual for New Construction and Overlays,” SHRP-A-407, Strategic Highway Research Program, National Research Council, Washington, D.C., 1994.
2. Horonjeff, R. and McKelvey, F.K. *Planning and Design of Airports*, Third Edition, New York, McGraw-Hill, 1983.
3. Yoder, E.J. and Witczak, M.W., *Principles of Pavement Design*, Second Edition, New York, John Wiley & Sons, Inc., 1975.
4. “Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types,” Manual Series No. 2 (MS-2), Sixth Edition, Asphalt Institute, Lexington, Kentucky, 1995.